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Microtrench depth and width of SiON plasma etching

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Abstract

Silicon oxynitride films were etched in a C_2F_6 inductively coupled plasma. In all experiments, microtrenching occurred at the feet of the profile sidewall. The microtrenching was characterized in terms of maximum depth and width. Each characteristic was examined as a function of the process parameters, including radiofrequency source power, bias power, pressure, and C_2F_6 flow rate. Apart from the etch mechanisms, relationships between microtrenching and profile angle were also identified. Profile angle variation played an important role in understanding depth variation. The width of microtrenching increased with increasing the source or bias power. In contrast, increasing the C_2F_6 flow rate decreased the width. Effect of process parameters on microtrenching at various plasma conditions was characterized by using a statistical experimental design. Smaller depths and widths were obtained at lower source and bias powers. The main effect analysis revealed that the bias power had a considerable impact on both characteristics.

Keywords: Plasma etching; Silicon oxynitride film; Microtrenching; Width; Depth; Optimization

1. Introduction

Silicon oxynitride (SiON) films have been extensively studied since SiON is a promising material for manufacturing optical and electronic devices [1–3]. In manufacturing optical waveguides, SiON films enable a high refractive index contrast to be achieved between the core and cladding layers. Other features attractive for manufacturing microelectronic devices include the low density of surface states, high dielectric permittivity, and the controllability of band energy in terms of [O]/[N] ratio [4]. SiON films etched in a C_2F_6 inductively coupled plasma (ICP) have been recently studied as a function of process parameters [5], where the etch rate and profile angle were characterized and optimized in conjunction with a statistical experimental design. Interestingly, in nearly all experiments, microtrenching occurred. A similar microtrenching has been experimentally observed during the etching of silicon carbide [6] and oxide [7]. Several analytical [8–10] or empirical [11] simulation models have been reported. The microtrenching is generally attributed to enhanced ion flux and/or ion bombardment at the base (or feet) of the profile sidewall. This aspect has been studied as a function of ion angular spread [9], or by fitting an analytical model to the images taken by a scanning electron microscope (SEM) [10]. During the silicon dioxide etching, the bias power effect on the microtrenching has experimentally been examined [7]. Until now, there have been few experimental reports on microtrenching as a function of process parameters.

In this study, an SiON film was etched in a C_2F_6 ICP and microtrenchings of etched features were studied experimentally as a function of the four process parameters, including the source power, bias power, pressure, and C_2F_6 flow rate. A microtrenching geometry (MG) was characterized in terms of the depth and width. To our best knowledge, this is the first report on the MG of SiON films. Empirical relationships between the profile angles and MG were identified. A statistical experimental design was applied not only to calculate the main effects of process parameters, but also to empirically optimize the MG.

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2. Experimental details

A schematic diagram of the ICP etch system is shown in Fig. 1. Plasma is generated inside a chamber and isolated from planar-coupled coils by a dielectric quartz window. A multipolar magnet was additionally mounted outside the chamber to achieve high plasma density while maintaining high spatial uniformity. The cylindrical chamber has a radius and height of 80 and 40 mm, respectively. Prior to feeding etching gases, the chamber is evacuated using a turbo (TUROVAC 3430 MC) pump and a rotary (Edward High Vacuum E2M40) pump, thereby maintaining a base pressure of 0.133×10^{-3} Pa. Gas flow rates are precisely controlled through mass flow controllers, and the process pressure measured by a baratron gauge is controlled with a throttle valve. A coolant is fed to the chuck holder to minimize damage to the equipment from a surge in the substrate temperature during etching.

Test patterns were fabricated on SiON wafers. Using a plasma-enhanced chemical vapor deposition system, SiON films were deposited to 4.09 μm thickness at 150 W rf power, 135 sccm N_2O flow rate, and 45 sccm SiH_4 flow rate, 350 °C substrate temperature, and 26.6 Pa pressure. The refractive index of the deposited SiON films was 1.46. To fabricate a Ni mask layer, photoresist patterns were first formed. The magnetron sputtering method was used to subsequently deposit Ni films of 0.3 μm thickness on the patterned photoresist. The sputtering continued for 1 h at 1.06 Pa pressure, 100 W rf power, and 6 sccm Ar flow rate. By removing the photoresist with acetone, an Ni mask layer was formed. The SiON films were etched in a C_2F_6 ICP. In all experiments, the etching time was set to 10 min. Using an SEM, both depth and width of the microtrenching were measured as illustrated in Fig. 2. Here, the depth corresponds to the maximum depth obtainable for the microtrenching. To facilitate the interpretation of the microtrenching, the profile angles were also measured using the SEM. In Fig. 2, the profile angle was denoted as "A".

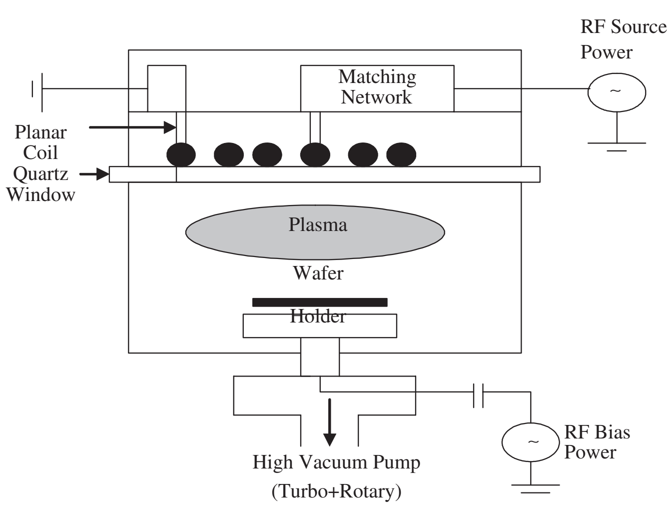

Fig. 1. Schematic of inductively coupled plasma etch system.

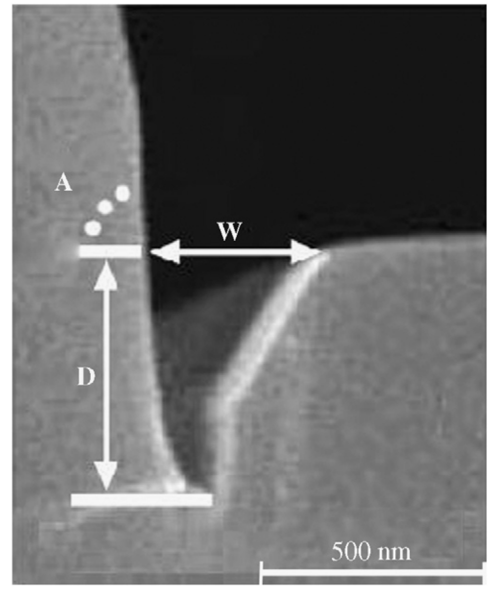

Fig. 2. SEM profile for the measurements of microtrenching depth and width.

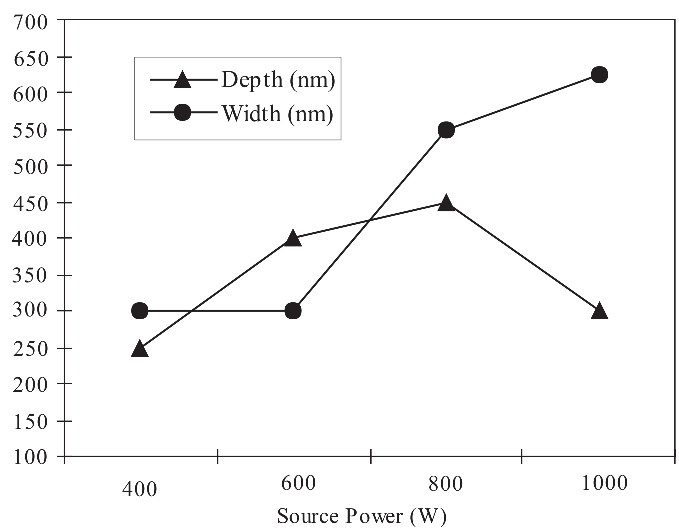

Fig. 3. The source power effect on microtrenching depth and width.

3. Results

3.1. Effect of rf source power

Fig. 3 shows the MG as a function of the source power. The bias power, pressure, and C_2F_6 flow rate were set to 60 W, 1.2 Pa, and 45 sccm, respectively. As shown in Fig. 3, the depth increases with increasing the source power from 400 to 800 W. Increasing the source power enhances plasma density and concentration of reactive etch radicals. The profile angle increased from 81° at 400 W to 84° at 800 W. The larger profile angle enables more ions to focus on the profile sidewall. Moreover, the profile at 800 W was bowed. The bowed sidewall is likely to concentrate more ions onto the profile base [12]. All these variations serve to